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Conservation of the K-quantum number in warm nuclei

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The selection rules on the K-quantum number in rapidly rotating warm nuclei are investigated analyzing quasi-continuum spectra feeding into low-K and high-K bands in ^{163}Er. The data are compared to simulated spectra obtained using the band mixing model predictions including the residual interaction and a term representing the effect of the K-quantum number on the rotational energy. K-selection rules are found to be obeyed by the decay along excited unresolved rotational bands of heat energy up to around 1.2 MeV and angular momentum $30\hbar \leq I \leq 40\hbar$. In contrast, the results corresponding to higher heat energy of 1.2 to 2.5 MeV indicate that the selection rules are only partially satisfied.

1. Introduction

The study of nuclear states with high values of the K-quantum number is interesting both from the point of view of the decay out from such states but also in connection with their feeding, which allows to investigate the validity of the associated selection rules at higher excitation energies. In fact, as it was stated by B.Mottelson [1] the question of K-quantum number violation in thermally excited states is a key issue in the study of the transition between ordered and chaotic many-nucleon motion caused by the residual

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interaction and the high level density. In this paper we present a new study of the warm rotational motion in the ^{163}Er nucleus based on the measurement of the γ-transitions forming quasi-continuum patterns in $\gamma-\gamma$ spectra and populating specific configurations with different values of the K-quantum number.

2. The experiment

The experiment was carried out using the EUROBALL array at the IReS Laboratory (France), employing the reaction ^{18}O + ^{150}Nd, at E_{beam}= 87 and 93 MeV. The corresponding maximum angular momentum reached in the reaction has been calculated to be 40 and 45 $\hbar$, respectively [2]. A matrix collecting the entire decay flow of ^{163}Er (named *total*) has been constructed together with matrices gated by transitions belonging to the low-K (K=5/2) signature and parity configurations labeled A=(1/2,+), B=(-1/2,+), E=(1/2,-) and F=(-1/2,-) in ref. [3], and by the high-K (K=19/2) bands labeled K1= (0,-), K2=(0,+) and K4=(1,+) in ref. [3]. Panel a) of figure 1 shows an example of a cut in the *total* matrix perpendicular to the $E_{\gamma_1} = E_{\gamma_2}$ diagonal at the average transition energy $(E_{\gamma 1} + E_{\gamma 2})/2 = 900$ keV, 60 keV wide.

The fluctuations of counts in each channel of the selected $\gamma - \gamma$ spectra, expressed as variance and covariance, are evaluated by the program STATFIT [4,5] and stored into matrices. Because each rotational E_γ-cascade contributes on the average one count in each $\frac{4\hbar^2}{\Im}$ interval, the statistical moments are evaluated over sectors of $\frac{4\hbar^2}{\Im}\times\frac{4\hbar^2}{\Im}$, corresponding to 60 keV×60 keV intervals for rare earth nuclei around ^{163}Er. From the fluctuation spectra we extracted the effective number of decay paths.

3. Results and conclusions

The number of paths obtained from the analysis of the first ridge of the 2D *total* matrix ($\approx$ 45) is shown in figure 1 and compared with the predictions of different type of calculations. As one can see, the calculations without residual interaction (dashed line) fail to reproduce the data while a better agreement is obtained including the residual interaction plus an additional term representing the effect of the K-quantum number on the rotational energy, named as J^2-term (full line). The number of paths obtained from the analysis of the first ridge of the $\gamma - \gamma$ matrices gated by individual bands is found in total to be around ≈ 20 for the four low-K and the three high-K configurations (panel c) in figure 2). This is in good agreement with the predictions including the residual interaction plus the J^2-term. In contrast to the ridge analysis, the number of paths obtained from the valley region is found to depend significantly on the nuclear configuration (panel d) in figure 2). This latter result intuitively suggests that the mixing process is indeed different for high-K and low-K states in the region where the rotational bands are strongly mixed.

The lines shown in figure 2 correspond to the analysis of simulated $\gamma - \gamma$ spectra constructed by a Monte Carlo code [6,7] using the levels and E2 transition probabilities microscopically calculated for the specific ^{163}Er nucleus [8]. In addition, statistical E1 transitions are included in a schematic way using the calculated level density and a GDR strength function corresponding to a prolate nucleus with deformation $\beta = 0.25$. The code was recently improved including an exponential quenching factor that takes into account

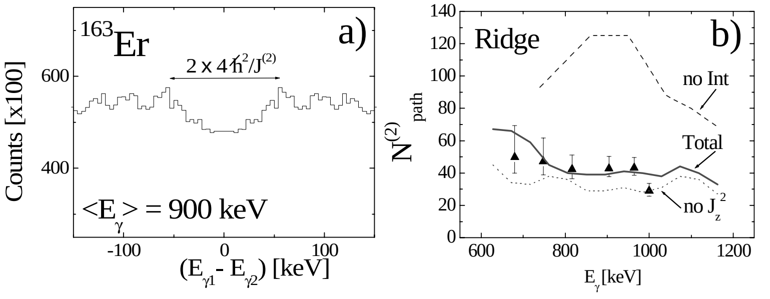

Figure 1. *Panel a)*: example of cut perpendicular to the main diagonal in the *total* matrix, at the average energy $(E_{\gamma1}+E_{\gamma2})/2 = 900$ keV, with a width of 60 keV. The symmetrically spaced ridges are indicated by the arrows. *Panel b)*: the experimental number of paths (full triangles) extracted from the total matrix with the fluctuation analysis. The data are compared to the total number of bands directly extracted from band mixing calculations: the dashed line is obtained when no residual interaction is taken into account, the dotted one when only the two body residual interaction is considered and the full line when all the terms (residual interaction and J^2-term) are included.

the difference in K-quantum number between the initial and final states. Such factor is analogous to the one employed in the analysis of the E1 decay-out from isomeric states [9,10]. Each γ-cascade is started from initial values of internal energy and spin randomly chosen among a two-dimensional entry distribution of Gaussian shape, with centroids and widths reproducing the experimental conditions (i.e. $< U > = 4$ MeV, $FWHM_U = 4$ MeV, $< I > = 44\ \hbar$, $FWHM_I = 20\ \hbar$). The choice of these parameters for the entry points and E1 transition probability resulted in a good reproduction of the measured intensities of both ridge structures and low spin yrast transitions [6].

A covariance analysis of the ridge and valley structures investigating the common transitions feeding low- and high-K configurations was also performed. Also in this case, the covariance results indicate a conservation of the selection rules for the ridge structure and only a partial conservation for the valley region [11].

In conclusion, we have addressed the problem of the onset of K-mixing in rapidly rotating warm nuclei by studying the γ transitions forming the quasi-continuum in the ^{163}Er nucleus and comparing it to the theory. The experimental results from the fluctuation analysis on γ-γ coincidences of transitions forming the ridge structure and covering the spin region 30-40 $\hbar$ with heat energies up approximately 1 MeV point to a good conservation of the K quantum number. At higher internal energy ($U \sim 1.2$ to 2.5 MeV), probed by the weaker and more numerous transitions forming the valley, a partial conservation of the K quantum number is found. To shed more light on this problem studies on high K-bands of larger internal energies will be extremely useful.

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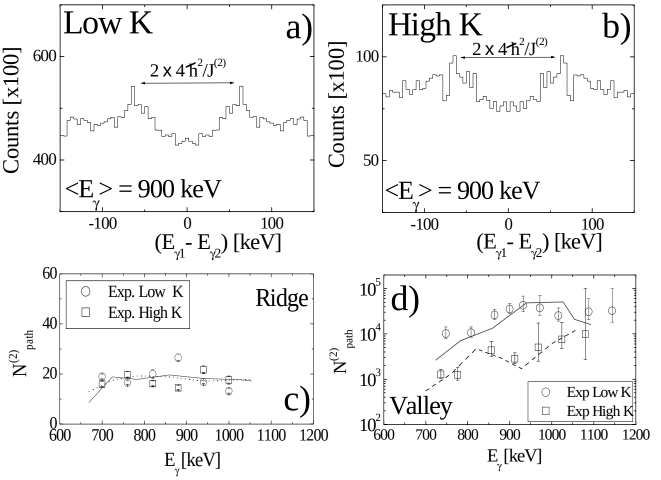

Figure 2. *Panel a) and b)*: examples of cuts perpendicular to the main diagonal at the average energy of 900 keV and width of 60 keV performed on gated matrices: panel a) refers to low-K configurations and panel b) to high-K ones. The symmetric ridges are indicated by the arrows. The bottom panels show the number of paths extracted from the fluctuation analysis of the ridge (c)) and the valley (d)). Experimental data are represented by symbols (open circles for low-K configurations and open squares for high-K ones) while the results from the simulation are shown by lines (full line for low-K and dashed line for the high-K).

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REFERENCES

[1] B.R. Mottelson, Nucl. Phys. **A557** (1993)717c.
[2] S. Leoni, Phys. Rev. Lett. **93**(2004)022501-1.
[3] G.B. Hagemann et al., Nucl. Phys. **A618**(1997)199.
[4] T. Døssing et al., Phys. Rep. **268**(1996)1.
[5] S. Leoni et al., Nucl. Phys. A671(2000)71.
[6] A. Bracco et al., Phys. Rev. Lett. **76**(1996)4484.
[7] A. Bracco et al., Nuc. Phys. **A673**(2000)64.
[8] M. Matsuo et al., Nucl. Phys. **A736**(2004)241.
[9] P. Walker et al., Phys. Lett. **B408**(1997)242.
[10] F.G. Kondev et al., Nuc. Phys. **A632**(1998)473.
[11] G. Benzoni et al., to be published.